Discharge studies in a Triple-GEM detector

Summer student project

Conseil Européen pour la Recherche Nucléaire (CERN)

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Contents

1 Motivation

The aim of this summer student project was to perform measurements on GEM long-term stability and possible harmful effects of discharges on the performance of GEM detectors. Related to this, we wanted to get a deeper understanding of the nature of discharges and to contribute with yet another point of view to the several discharge studies that have already been performed and to those that are still ongoing.

For a closer investigation of what happens in a GEM detector when a discharge occurs, one needs to define discharges in a qualitative and a quantitative way. Thus, one needs to find out in which of the GEMs in a multi-GEM detector the discharge takes place, what the time interval between two consecutive discharges is and how much energy a discharge releases. Defining and measuring all these qualities and quantities should provide a better understanding of the still not understood processes of GEM discharging.

Special emphasis in the measurements was laid on propagated discharges. Just recently, in April 2016, a group working on the ALICE TPC upgrade that is using GEMs was measuring discharge propagation with a time interval of $O(10\mu s)$. This was a new phenomenon; up to this point, propagated discharges were thought to be caused only by electrons and photons, with a delay of up to $O(100ns)$.

This time scale of $O(10\mu s)$ would be appropriate for ions. Therefore, ions were added to the mechanisms triggering a propagated discharge. We tried to repeat some of the measurements the mentioned group performed, with added sensitivity to what happens in the different stages of the GEM detector. The results of these measurements will be described in the following chapters.

2 Setup

The setup shown in figure 1 consists of: a Triple-GEM detector, the makeshift antennas and two oscilloscopes. At the beginning of the project, a Tektronix 2024C oscilloscope with a bandwidth of 2 GS/s was used. After figuring out that the time resolution of this oscilloscope is not sufficient for the measurements we were performing, it was replaced with a LeCroy 104mxi-a oscilloscope with a bandwidth of up to 10 GS/s, leaving the Tektronix oscilloscope as a backup if needed.

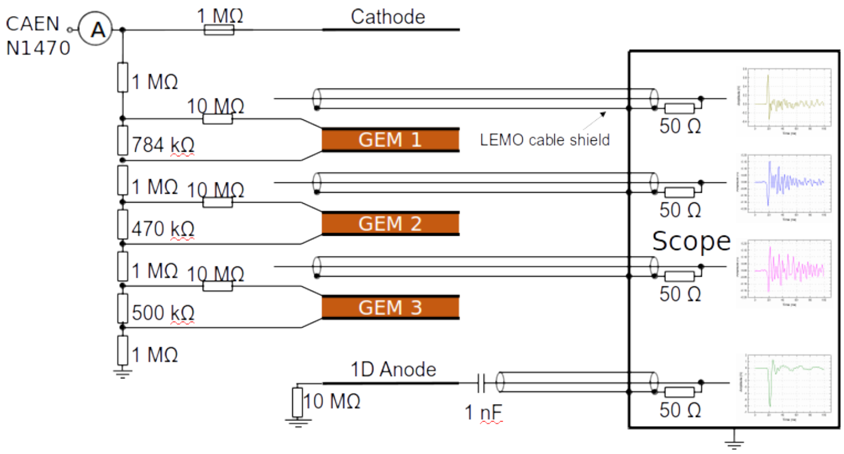

Figure 1: Schematic drawing of the setup with makeshift antennas.

2.1 Detector

For all measurements, a Triple-GEM detector was used. None of the GEM foils in this detector were fresh out-of-the-box, they were rather already used in other measurements but found to be still working. In one corner of the Kapton entrance window a hole was pierced, allowing α-radiation emitted by a radioactive source to enter the detector. A 0D readout plane was glued to the bottom of the readout board. Using such a 0D anode was necessary to reduce reflections in the picked-up signals of the makeshift antennas, described later on. With the new PCB antennas (also described later on), it has to be checked whether using two-dimensional readout makes a difference in comparison to using a zero-dimensional anode.

The detector is powered by a CAEN N1470 and N1471 power supply, respectively, through a resistor chain. An Ar-CO2 gas mixture is used to flush the detector volume.

The GEM foils were of "standard" format, meaning that had a hole diameter of 70 µm at a pitch of 140 µm. The gaps in the detector between the different stages were: 3 mm drift, 2 mm transfer 1, 2 mm transfer 2, and 2 mm induction. At a certain point, GEM2 had to be replaced by another foil, since the resistance across the GEM dropped to 50 M Ω. At the creation of this document, the other foils were still intact, with the exception of GEM1 having a lot of "burn marks" in the irradiated area below the hole of the entrance window.

2.2 Antennas

For the measurements described in Section 3, the makeshift antennas from fig. 1 were used. Those antennas were cut out of a PCB board, with two conducting strips on the bottom of the antenna. One strip was connected to the pin hole on one side and to the resistor chain on the other side; to the other strip a LEMO connector was soldered, providing the connection to the oscilloscope. Such an antenna was attached to each of the upper GEM electrodes, allowing to pick up the response signal in the resistor chain when a GEM discharged.

The working principle of the antennas is inductive coupling or magnetic field coupling: energy is coupled from one circuit to another with a magnetic field. This coupling occurs when the magnetic field lines induced by a current in one of the circuits pass through the loop formed by the other circuit. Thus, having such antennas attached to the feedthroughs of the GEMs, the change of current induced by a discharge in the strip soldered to the feedthrough will be picked up by the other strip via inductive coupling. The oscilloscope then converts the current into a voltage signal which is displayed on the screen. With the antennas one can determine exactly which of the GEMs (see fig. 4) in the detector was discharging, with a time resolution in the nanosecond scale.

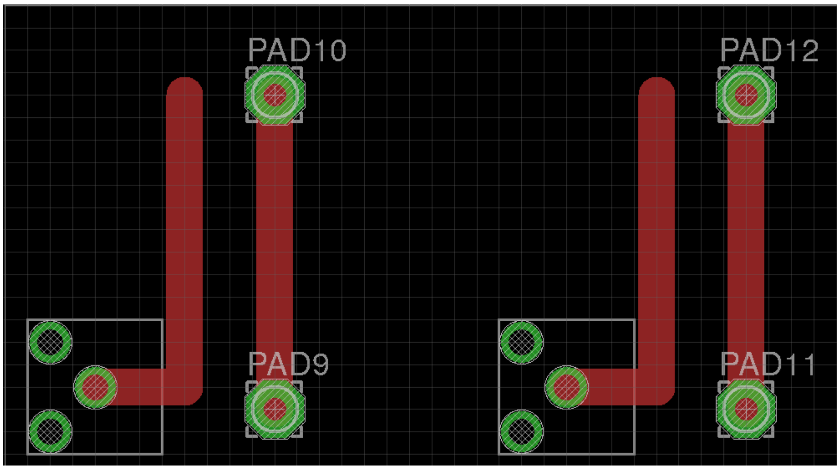

Figure 2: The design of the antennas. One pair of strips is attached to top and bottom of a GEM, respectively.

After some time having the makeshift antennas in operation, they started to break, producing discharges between the two strips. Thus, we decided to design PCB boards making use of the same principle of parallel strips as the antennas, but designed in a

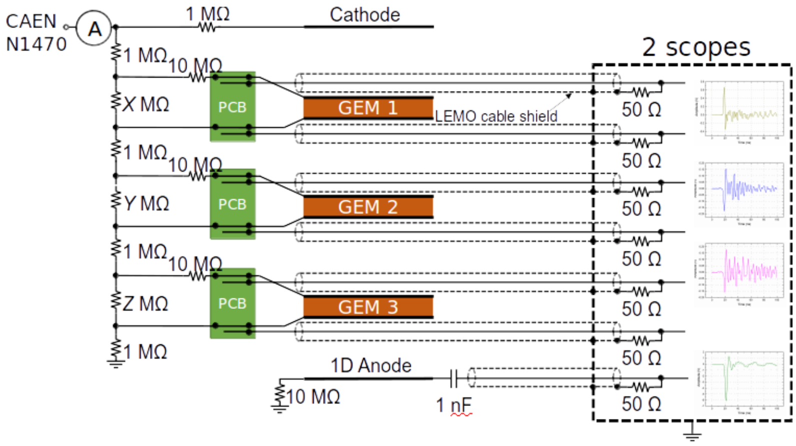

Figure 3: Schematic drawing of the setup with the PCB antennas.

more sophisticated way (fig. 2).Three different sets consisting of six antennas each were produced, such that there is an antenna available for top and bottom of every GEM electrode.

The schematic drawing of the new setup is shown in fig. 3.

3 Methodology

3.1 Discharge pattern

First of all, we had to find out how a discharge in a GEM looks like. Our approach was to set the potential difference across one of the GEM electrodes to the Paschen limit while keeping the potential difference across the other two GEMs far from it; doing this, one can ensure that only the GEM close to the limit will discharge. The outcome of these investigations is shown in fig. 4.

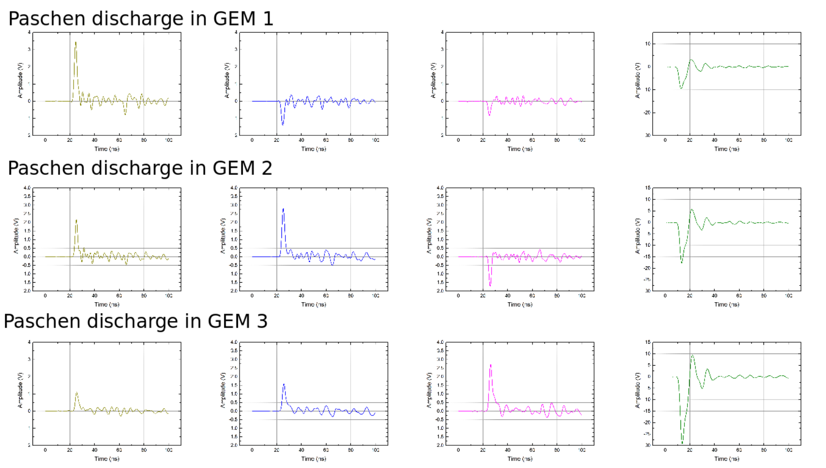

Figure 4: Pattern for discharges in GEM1, GEM2 and GEM3. For a discharge in GEM1, the pattern is up-down-down-down; a discharge in GEM2 corresponds to up-up-down-down and one in GEM3 to up-up-up-down.

Depending on where the GEM was discharging, an unique signal pattern is displayed on the oscilloscope which is then unambiguously identified with a discharge in a certain GEM. For example, a discharge in GEM 2 induces a positive signal in the antennas attached to the first two GEM electrodes, whereas the signal in GEM 3 and in the anode is negative. According to the pattern, a discharge can be identified by the change of polarity in the channels.

3.2 Propagated discharges

As known from previous measurements on discharge propagation, the onset of propagation begins at a certain value of the transfer field; below this threshold, the propagation probability is zero.

As a first step, we wanted to change the value of the electric field E_{T1} in the transfer gap between GEM 1 and GEM 2 to see if we are able to induce propagated discharges. For all these measurements, the potential difference across each stage of the GEM was held constant, except for E_{T1}. The values used for each stage can be found in table 1.

Stage	R [kΩ]	ΔV	Gap [mm]	E [kV/cm]
Drift	480	300	3.00	1.0
GEM 1	784	490	0.05	98.0
Transfer 1	variable	variable	2.00	variable
GEM 2	470	294	0.05	58.7
Transfer 2	1000	625	2.00	3.1
GEM 3	500	313	0.05	62.5
Induction	1000	625	2.00	3.1

Table 1: Values of the different stages of the GEM detector. Only T1 was varied during the measurements.

The potential difference across GEM 1 was well below the Paschen limit 5.42 MeV α-particles from an Am-241 source were used to induce discharges in the first GEM. Triggering on this initial discharge, we could acquire waveforms showing us what happens after that.

E_{T1} was varied from 3.6 kV/cm up to 10.1 kV/cm. For each value of E_{T1}, at least one sequence of 100 waveforms with a time interval of 20 μs was acquired.

As a second step, we planned to vary also the value of the transfer fields in the gap between GEM 2 and GEM 3 as well as in the induction gap in the same way as we did with the field in the first transfer gap, while keeping the field in the other gaps constant. However, there was not enough time to perform those measurements in great detail. Preliminary results will be discussed in the next section.

4 Results

Analysis of the data was performed by using a custom-made python script.

4.1 Violation of discharge pattern

First, there has to be distinguished between different signals. What is called a "propagated discharge" or what is referred to by that term in other works presented might not be a discharge in a GEM, but an event that takes place in the gap between two electrodes. Thus, "propagated discharge" is not the appropriate term, we will refer to it from now on as "secondary signal". Here the question arouses, what discharge propagation in fact is; from the waveforms acquired during the measurements, it can be seen that a single event does not consist of just the primary discharge and the secondary, but of several discharges in between. More of this will be discussed later. There are two reasons that give evidence that the secondary might be of different origin: The first reason is that looking at a sample waveform, one can distinguish between two different signal shapes, as can be seen in fig. 5. One signal has a very sharp rising edge and a width of a few nanoseconds, while the other one looks smoother and more evenly distributed, with a width of tens of ns.

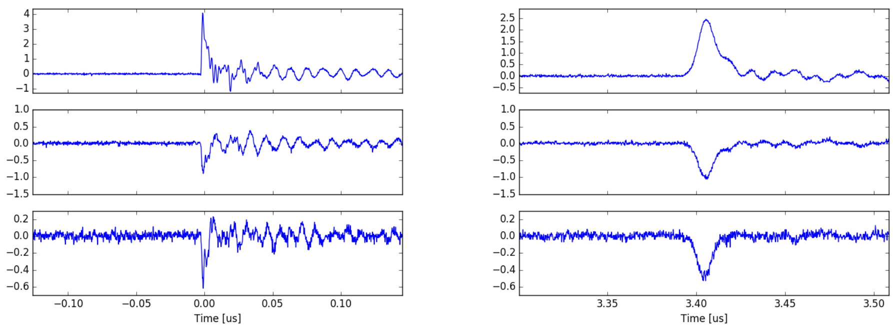

Figure 5: Sample waveform of an event in channel 1. The signal left corresponds to a discharge in GEM1, while the signal right does not correspond to any of the discharge patterns.

Second, using the PCB antennas and the additional information they give us, one can expand the discharge pattern from the previous section to the six available channels shown in fig. 6.

What we found out, given this new information, was that the change of polarity when a GEM is discharging actually happens in the GEM electrode itself, between top and bottom. However, for the signal with a different shape, this is not true; here, the change in polarity of the signal actually takes place in the gap.

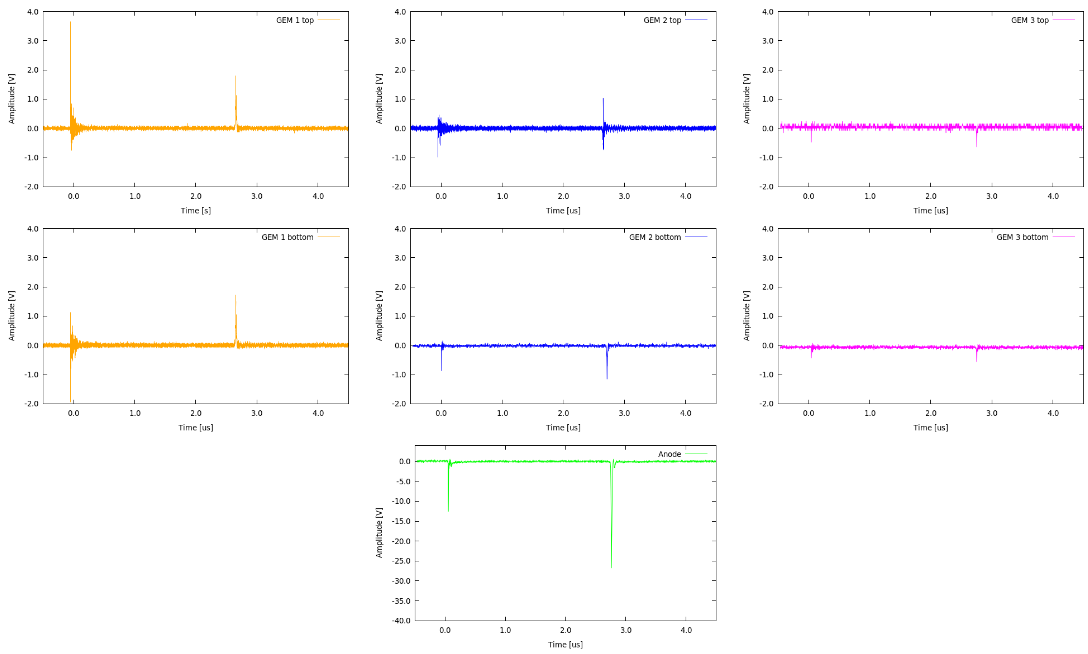

Figure 6: Waveforms obtained from each GEM, both top and bottom. The waveforms show the initial discharge, followed by a secondary with a discharge in GEM 2 simultaneously.

4.2 Discharge propagation probability

The propagation probability from GEM1 to GEM2 relies strongly on the transfer field applied between the two GEMs, as shown in Fig. 7. For this plot, only propagated discharges in the μs regime were taken into account.

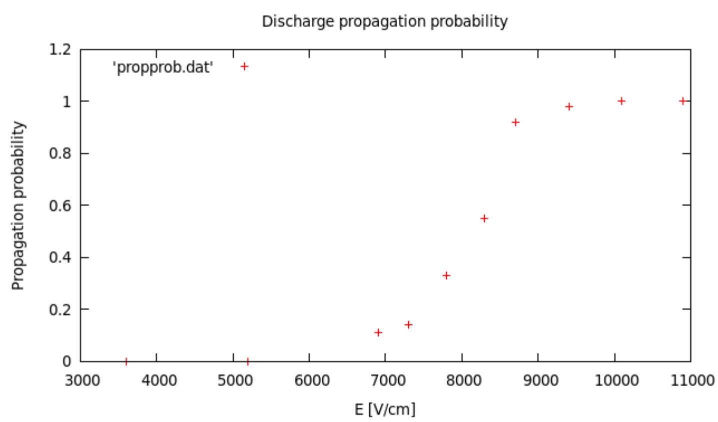

Figure 7: Discharge propagation probability from GEM1 to GEM2 over different values for the transfer field in between.

4.3 Time interval between two consecutive discharges

Fig. 8 shows the peak-to-peak time difference between the first discharge and the secondary signal for different values of E_{T1}, in comparison with the time it would take ions to travel through the gap for the fields and gas mixture used. From the plot one can read that the response of the secondary signal is much faster than ions travelling through the gap could be, theoretically.

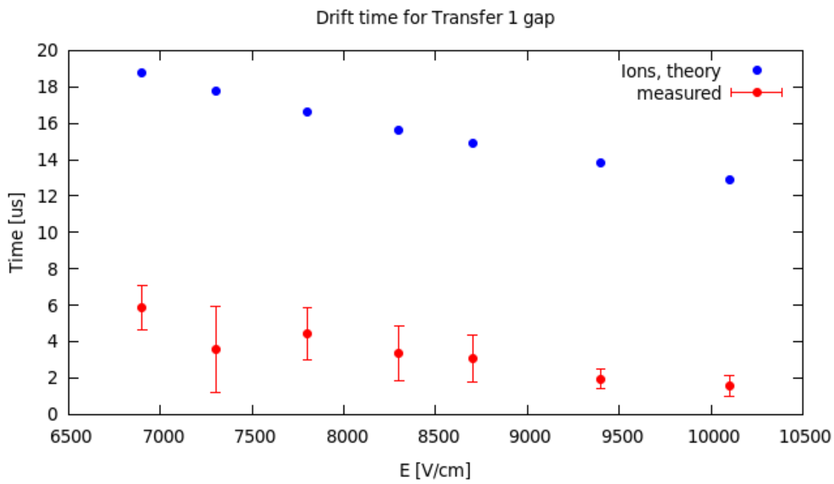

Figure 8: Time interval between initial and propagated discharge in μs regime.

4.4 Other observations

Having all these numbers and plots obtained with varying E_{T1}, we took a closer look onto the actual waveforms. Most of them seem to follow a pattern: every time, the order of the discharges was: first discharge in GEM 1, after that a discharge in GEM 2, and then the secondary signal. A sample is shown in fig. 9.

The discharge in GEM 2 always happens between the initial discharge and the secondary signal. However, in many cases the discharge in GEM 2 overlaps with the secondary (see fig. 10).

There was one measurement taken with E_{T2} set at 9.4 kV/cm. Here, the picture looks a bit different - the order of discharges is GEM 1-GEM 2-GEM 3-secondary, as can be seen in fig. 11.

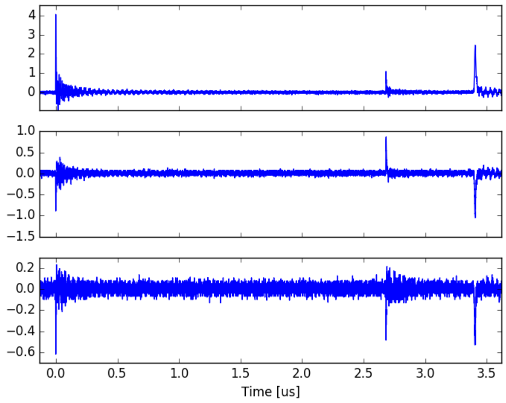

Figure 9: Sample waveform of E_{T1} scan, one can see the order of the discharges: GEM 1-GEM 2-secondary.

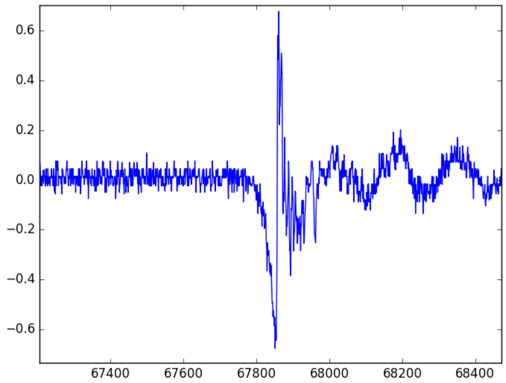

Figure 10: Overlap of GEM 2 discharge and secondary signal in the waveform of GEM 2 (arbitrary timescale).

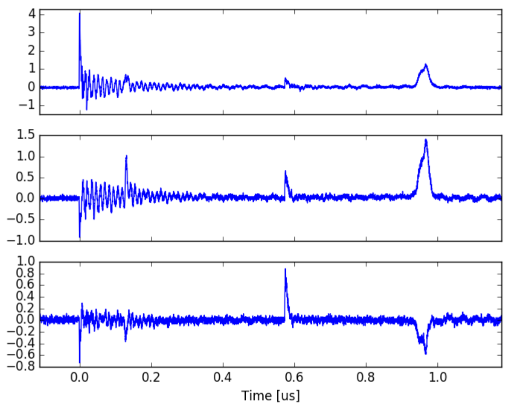

Figure 11: Sample waveform of E_{T2} at 9.4 kV/cm, one can see the order of the discharges: GEM 1-GEM 2-GEM 3-secondary.

5 Summary and Outlook

During the summer, a lot of measurements have been performed, giving new insights on the processes involved in GEM discharges. They rather pose new questions than give answers, but they are placing certain restraints on the origin of the sparks. While it seems that propagated discharges of GEMs are more or less well understood, the secondaries are still not fitting perfectly in the picture. From previous measurements the time scale involved points to ions as originators of the discharge; however, the observations described in 4 show that the time scale of the events is unreachable for ions.

In addition, there are more things that have to be taken into account. How does a spark in a GEM electrode alter the field in the gaps above and below it? What happens to the voltage drop in the GEM when a spark occurs? Does it drop to zero or not? Why does the discharge in a GEM often coincide with a secondary happening in the field above? To increase the understanding of discharges, one has to find an answer to these questions. One the one hand, simulations with PSPICE and COMSOL might help here, but on the other hand, there will be no way around more measurements to increase the amount of valid data.

With the PCB antennas, one has a powerful instrument that provides great detail of what happens in the GEM. Using the antennas together with two high bandwith oscilloscopes and the analysis code, it should be possible to shed light on the still not understood discharge events.

One goal of this project was also to quantify the long-term stability of GEMs. We have started with measurements of single hole discharges with ten year old foils, but so far the experimental conditions do not seem to mimic the conditions under which a GEM is in operational mode. However, for the measurements, several thousand discharges were induced at the Paschen limit and with an α-source. The top GEM foil, being heavily irradiated and being involved in each discharge event, still works, as well as the GEM 3 electrode used in the setup. Taking into account that those foils were already used before and that they were exposed to conditions that are highly unlikely to occur during normal operation, it seems that the GEMs are still quite reliable.

List of Figures

List of Tables